# Causal Premise Semantics

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# Outline

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1. Premise Semantics
   - Modals
   - Conditionals
   - Counterfactuals
2. Implementation
   - Premise sets
   - Premise set sequences
   - Modals and conditionals
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   - Basics
   - Modal base
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# Premise Semantics for modals

Kratzer (1981a)

(1) John must be at home. *Must*(*John home*)

(2) John may be at home. *May*(*John home*)

- Two contextually given bodies of *background assumptions*:
  - Modal base: what is *established* in the relevant sense
    - epistemic (subjective; beliefs)
    - circumstantial (objective; facts)
  - Ordering source: what is *preferred* in the relevant sense
    - stereotypical (normalcy)
    - deontic (obligations)
    - bouletic (desires)

➠ Variety of modal flavors

- *[In view of the curfew,]* John must be at home.
- *[In view of what we know,]* John may be at home.

# Premise Semantics for modals

Kratzer (1981a)

(1) John must be at home. *Must*(*John home*)

(2) John may be at home. *May*(*John home*)

(3) Prejacent: John is at home. *John home*

- Interpretation relative to two sets of propositions:
  modal base $M$; ordering source $O$
- Try all ways of adding propositions from $O$ to $M$, maintaining consistency.
  - If you inevitably get a set that entails (3), then (1) is true.
  - If there is a way to keep adding without ruling out (3), then (2) is true.
- Terminology
  - Premise set: a consistent set of propositions containing $M$ and some subset of $O$.
  - $\text{Prem}^K(M, O)$: the set of all premise sets obtained from $M, O$.

# Premise Semantics for conditionals

Kratzer (1981a)

(4) If the lights are on,
John must be at home. $Must_{lights\ on}(John\ home)$

(5) *Antecedent:* The lights are on. *lights on*

(3) *Consequent:* John is at home. *John home*

- Evaluate the consequent on the supposition that the antecedent is true.
  1. Add the antecedent (temporarily) to the modal base;
  2. Evaluate the matrix clause relative to the modified modal base.

➡ $Must_{lights\ on}(John\ home)$ is true relative to $(M, O)$ if and only if $Must(John\ home)$ is true relative to $(M{+}lights\ on, O)$.

# Premise Semantics for counterfactuals

Goodman (1947); Kratzer (1981a,b, 1989); Kaufmann (2012)

(6) If that match is scratched, it will light. [indicative]

(7) If that match were scratched, it would light. [counterf.]

(8) If that match had been scratched, it would have lit. [counterf.]

- *'will'* and *'would'* are *modals*.
  Present and Past of an underlying modal stem *'woll'* .
  (Abusch, 1997, 1998; Condoravdi, 2002; Kaufmann, 2005)
- *'would'* marks *counterfactuality*.
  Adding the antecedent to *M* requires adjustments to avoid inconsistency. (Stalnaker, 1975; Iatridou, 2000; Schulz, 2012)
- I am glossing over some morphological details in this talk.
  (Kaufmann, 2005; Grønn and von Stechow, 2011; Schulz, 2008, 2012)
- I am interested in *objective* readings of counterfactuals (circumstantial modal base, stereotypical ordering source)

# Premise Semantics for counterfactuals

Goodman (1947); Kratzer (1981a,b, 1989); Kaufmann (2012)

(8) If that match had been scratched, it would have lit. ✓

(9) If that match had been scratched, it would have been wet. ✗

Goodman's idea:

- When we say (8), we mean that conditions are such – i.e. the match is well made, is dry enough, oxygen enough is present, etc. – that "The match lights" can be inferred from "The match is scratched."
- [T]he connection we affirm may be regarded as joining the consequent with the conjunction of the antecedent and other statements that truly describe relevant conditions.

Q: What should be added to the antecedent?

- $\{scratched, was\ dry\}$ $\Rightarrow$ *lit*
- $\{scratched, didn't\ light\}$ $\Rightarrow$ *was wet*

# Premise Semantics for counterfactuals

Goodman (1947); Kratzer (1981a,b, 1989); Kaufmann (2012)

(8) If that match had been scratched, it would have lit. ✓

(9) If that match had been scratched, it would have been wet. ✗

Kratzer's formalization:

- The modal base *M* is empty.

  Thus the antecedent can be added consistently:
  $M{+}\mathit{scratched} = \{\mathit{scratched}\}$

- The propositions in *O* characterize the actual state of affairs.

➽ The premise sets favor similarity to what actually happened.

Two problems:

1. Still no explanation for the falsehood of (9)
2. Similarity to what happened is not (always) the right criterion.

# Premise Semantics for counterfactuals

Goodman (1947); Kratzer (1981a,b, 1989); Kaufmann (2012)

*[Two fair coins, A and B. Coin A was tossed and came up heads.]*

(10) If coin B had been tossed, it would have come up heads. ✗

- Falsehood of (10) not accounted for by similarity.

Two things are important in the construction of premise sets:

- what is/was the case ⇒ Modal base
- what is/was likely ⇒ Ordering source

➽ Need to hold on to *some of* the contents of $M$.

Q1: Which parts of $M$ to hold on to?

Q2: How to put those parts of $M$ together with bits of $O$?

# Premise Semantics for counterfactuals
## Kaufmann (2012)

(8) If that match had been scratched, it would have lit.

- Two ways of deriving premise sets from $M$, $O$:
  - by adding subsets of $O$ to $M$ (traditional)
  - by adding subsets of $O$ to subsets of $M$ (Kaufmann)
- Break up $M$, respecting its structure.
- The relevant structure is a contextual parameter, like $M$ itself.
  - temporal precedence *[wrong for cf but right for other expressions]*
  - causal dependencies *[right for cf and for yet other expressions]*
  - …
- Different structures ⇒ different interpretations.

BUT not all interpretations are attested for counterfactuals.

# Premise Semantics for counterfactuals

## Temporal interpretation: Re-run history

(8) If the match had been scratched (at $t_1$), it would have lit (at $t_2$).

- Propositions are indexed to times
- Modal base *M*: Completely characterizes history until now
  – i.e., inconsistent with the antecedent of (8)
- Collect all subsets *m* of *M* which
  - characterize *initial sub-histories* and
  - are consistent with the antecedent.
- $\text{Prem}(M, O)$ is the set of pairs $(m, o)$ such that
  - *m* is an initial sub-history consistent with *scratched*;
  - *o* is a subset of *O* consistent with $m + scratched$.
- In ranking these pairs, the *m*-part takes precedence over the *o*-part.

➡ Primary preference: long *m*; secondary preference: rich *o*.

BUT does this work for other counterfactuals? No.

# Premise Semantics for counterfactuals

## A problem for past predominance

*[A fair coin is about to be tossed. At $t_1$, you bet on heads. At $t_2$, the coin is tossed. At $t_3$, it comes up heads and you win.]*

(11) If I had bet on tails, I would have lost.

- Temporal precedence does not explain why (11) is true.
  - Before $t_1$, both heads and tails are possible.
  - Neither outcome is more likely than the other.
  - ➽ (11) is predicted to be false.
- What went wrong:
  The toss comes after the betting, yet is *unaffected* by it.
- Instead of temporal precedence, consider *causal precedence*.

# Premise Semantics for counterfactuals

## Causality

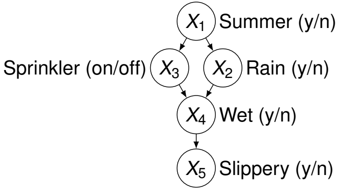
Pearl (2000):

(12) In the last decade, owing partly to advances in graphical models, causality has undergone a major transformation: from a concept shrouded in mystery into a mathematical object with well-defined semantics and well-founded logic ... Put simply, causality has been mathematized.

# Premise Semantics for counterfactuals

## Causal networks

- Causal network: ordered set $\langle U, E \rangle$
    - U: set of variables (questions)
    - E: asymmetric relation over U
    - Arrows indicate *causal influence*
- The answers to $X$'s parents determine how $X$ is answered. (Markov Assumption)



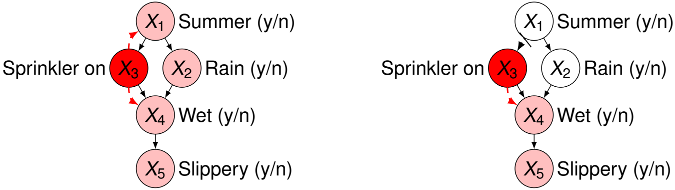
# Premise Semantics for counterfactuals
## Causal networks

- Two modes of inference:
  - Observation: *finding* the sprinkler on (left)
  - Intervention: *turning* the sprinkler on (right)
- Intervention is said to be involved in counterfactual inference.

(Pearl, 2000)

- This is true with some caveats

(Sloman and Lagnado, 2004; Dehghani, Iliev, and Kaufmann, 2012)

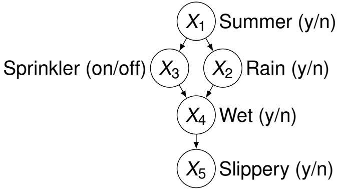


# Premise Semantics for counterfactuals

## Causal networks

Premise Semantics:

- No explicit representation of the graph.
- Rather: a characterization of the parameters that give rise to a causal interpretation.
  - Modal base: Contains answers to all questions in the graph (circumstantia – no epistemic ignorance)
  - Ordering source: Encodes, for each possible answer to $X$, how (un)likely it is given the settings of $X$'s parents, for all $X$

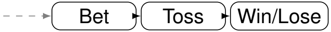


# Premise Semantics for counterfactuals

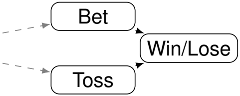
## Temporal vs. causal interpretation

(11) If I had bet on tails, I would have lost.

*Temporal order*




*Causal structure*




*Interruption:* Changing Bet discards everything after Bet.

*Intervention:* Changing Bet leaves the path to Toss intact.

- (11) is evaluated relative to pairs $(m, o)$, where:
  - $m$ is a subset of $M$, closed under *causal ancestors*
  - $o$ is a subset of $O$
  - in ranking pairs, $m$ takes precedence over $o$

➠ Similar to the temporal case, but relative to a non-linear order.

# Summary so far

A uniform rule for building premise sets from $M, O$:

- pairs $(m{+}Antecedent, o)$, where
  - $m$ is a subset of $M$, *subject to some condition* (initial history, closed under causal ancestors, etc.)
  - $o$ is a subset of $O$
  - in ranking these pairs, $m$ takes precedence over $o$.
- Observations:
  - If the antecedent is consistent with $M$, the internal structure of $M$ has no effect: In this case the highest-ranked pairs are of the form $(M{+}Antecedent, o)$.
  - ➠ Indicatives are not sensitive to the temporal/causal contrast.
  - Which way the modal base is split depends not only on the context: Counterfactual conditionals seem to favor a *causal* interpretation.
  - ➠ Is this the same for *all* counterfactual inferences, including those which arise with other linguistic expressions?

# Outline

# Kratzer Premise Semantics for modals

- Modal base $f$, ordering source $g$: functions from possible worlds to sets of propositions.
- Set of *Kratzer premise sets* for $f, g$ at world $w$:

$$\Phi := \{f(w) \cup X \mid X \subseteq g(w) \text{ and } f(w) \cup X \text{ is consistent}\}$$

- Proposition $p$ is a *necessity* relative to $\Phi$ iff

$$\forall X \in \Phi\ \exists Y \in \Phi\, [X \subseteq Y \text{ and } \bigcap Y \subseteq p]$$

  (*Possibility* is the dual.)

- $\mathit{Must}(p)$ is true at $f, g, w$ iff $p$ is a necessity relative to $\Phi$.

  $\mathit{May}(p)$ is true at $f, g, w$ iff $p$ is a possibility relative to $\Phi$.

- Notation: $\text{Prem}^K(f(w), g(w))$ instead of $\Phi$ for Kratzer premise sets.

# Kratzer Premise Semantics for conditionals

- Update of modal base $f$ with proposition $p$:

$$f[p] := \lambda w\, [f(w) \cup \{p\}]$$

- $\text{Modal}_p(q)$ is true at $f, g, w$ iff $\text{Modal}(q)$ is true at $f[p], g, w$.

# Basic idea

- Kratzer premise sets again:

$$\overset{K}{\text{Prem}}(f(w), g(w)) = \{f(w) \cup Y \mid Y \subseteq g(w) \text{ and } f(w) \cup X \text{ is consistent}\}$$

- Goal: "break up" $f(w)$.

$$\text{Prem}(f(w), g(w)) = \{X \cup Y \mid X \subseteq f(w), Y \subseteq g(w) \text{ and } \ldots\}$$

# Premise set pairs

- Let $f(w) = \{p, q\}$, $\quad g(w) = \{r, s\}$

  Then $\text{Prem}^K(f(w), g(w)) = \{\{p, q\}, \{p, q, r\}, \{p, q, s\}, \{p, q, r, s\}\}$

- *Premise background:* maps worlds to sets of sets of propositions.

  - $\mathbf{f}_{id}(v) := \{f(v)\}$ for all $v$. $\qquad \mathbf{f}_{id}(w) = \{\{p, q\}\}$

    $\mathbf{f}_{\wp}(v) := \wp(f(v))$ for all $v$. $\qquad \mathbf{f}_{\wp}(w) = \{\emptyset, \{p\}, \{q\}, \{p, q\}\}$
  - $\mathbf{g}_{\wp}(v) := \wp(g(v))$ for all $v$. $\qquad \mathbf{g}_{\wp}(w) = \{\emptyset, \{r\}, \{s\}, \{r, s\}\}$

- Cartesian product (writing ‘$X.Y$’ for $\langle X, Y \rangle$):

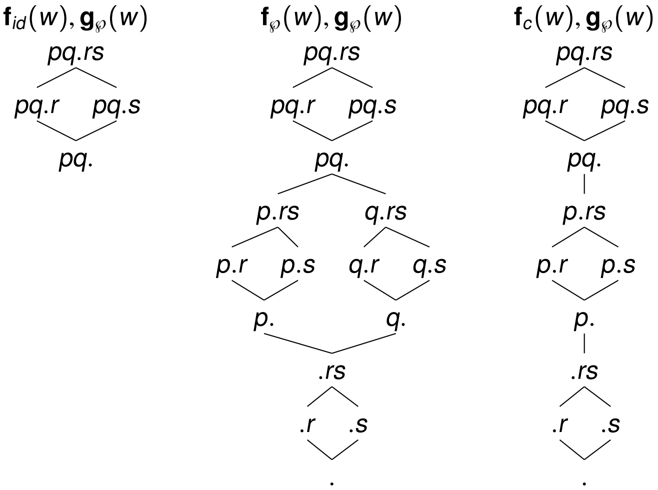
$$\mathbf{f}_{id}(w) \times \mathbf{g}_{\wp}(w) = \{pq., pq.r, pq.s, pq.rs\}$$

$$\mathbf{f}_{\wp}(w) \times \mathbf{g}_{\wp}(w) = \{., p., q., .r, .s, p.r, p.s, q.r, q.s, \ldots, pq.rs\}$$

- Lexicographic order:

$$X.Y \leq X'.Y' \text{ iff (i) } X \subseteq X' \text{ and (ii) if } X = X' \text{ then } Y \subseteq Y'$$

# Premise set pairs



# Premise set sequences

- *Sequence structures* recursively defined:
  - If $\Phi$ is a set of sets of propositions, then $\langle \Phi, \subseteq \rangle$ is a sequence structure.
  - If $\langle \Phi_1, \leq_1 \rangle, \langle \Phi_2, \leq_2 \rangle$ are sequence structures, then so is $\langle \Phi_1, \leq_1, \rangle * \langle \Phi_2, \leq_2 \rangle$, defined as $\langle \Phi_1 \times \Phi_2 \ , \ \leq_1 * \leq_2 \rangle$.

    (‘$*$’: lexicographic order)

Comments:

- Sequence structures are *partially ordered* (set inclusion for basic structures; preserved by lexicographic order)
- Product formation by ‘$*$’ is *associative* (since both Cartesian products and lexicographic orders are)

# Premise structures

- For logical properties, internal structure doesn't matter
  e.g., $X.Y$ is consistent iff $X \cup Y$ is

  For ranking among sequences, internal structure does matter.

- Given a sequence structure $\langle \Phi, \leq \rangle$:
  The *premise structure* $\mathrm{Prem}(\Phi, \leq)$ is the pair $\langle \Phi', \leq' \rangle$, where
  - $\Phi'$ is the set of *consistent* sequences in $\Phi$;
  - $\leq'$ is the restriction of $\leq$ to $\Phi'$.

- Proposition $p$ is a *necessity* relative to $\mathrm{Prem}(\Phi, \leq)$ iff

$$\forall X \in \mathrm{Prem}(\Phi, \leq)\ \exists Y \in \mathrm{Prem}(\Phi, \leq)\, [X \leq Y \text{ and } \bigcap Y \subseteq p]$$

  Possibility is the dual.

- Kratzer-style premise sets are a special case.

# Modals and conditionals

- *Must*$(q)$ is true at $\mathbf{f}, \mathbf{g}, w$ iff $q$ is a necessity at $\text{Prem}((\mathbf{f} * \mathbf{g})(w))$.

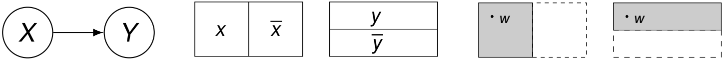
  *May*$(q)$ is true at $\mathbf{f}, \mathbf{g}, w$ iff $q$ is a possibility at $\text{Prem}((\mathbf{f} * \mathbf{g})(w))$.
- Hypothetical update of premise background $\mathbf{f}$ with proposition $p$:

$$\mathbf{f}[p] := \lambda w\,[\{\{p\}\} * \mathbf{f}(w)]$$

  - $\mathbf{f}_{id}[r](w) = \{\{r\}\} * \mathbf{f}_{id}(w) = \{r.pq\}$
  - $\mathbf{f}_{c}[r](w) = \{\{r\}\} * \mathbf{f}_{c}(w) = \{r., r.p, r.pq\}$
- *Modal*$_p(q)$ is true at $\mathbf{f}, \mathbf{g}, w$ iff *Modal*$(q)$ is true at $\mathbf{f}[p], \mathbf{g}, w$.

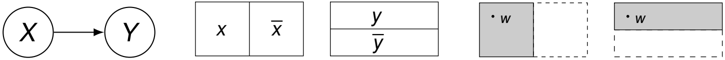
# Outline

# Basics




| **Causal Networks** | **Possible worlds** |
|---|---|
| Outcome | Possible world |
| Event | Proposition |
| Variable | Partition |

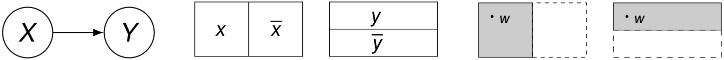
# Modal base




- A causal structure for $W$ is a pair $C = \langle U, < \rangle$, where
  - $U$ is a set of finite partitions on $W$;
  - $<$ is a directed acyclic graph over $U$.
- $\Pi^U$ (*causally relevant propositions*):
  set of all cells of all partitions in $U$.
- $\Pi^U_w$ (*causally relevant truths at w*):
  set of causally relevant propositions that are true at $w$.

- At each world $w$, the premise background $\mathbf{f}_c$ returns the set of those subsets of $\Pi^U_w$ that are *closed under ancestors*.

# Modal base



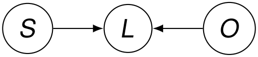

Let $X$ = *'whether it is sunny'*; $Y$ = *'whether the streets are dry'*

- $\mathbf{f}_c(w) := \{X \subseteq \Pi_w \mid X \text{ is closed under ancestors in } \Pi_w\}$
- $\Pi = \{x, \overline{x}, y, \overline{y}\}$
  $\Pi_w = \{x, y\}$ *[for $w \in xy$]*
  $\mathbf{f}_c(w) = \{\emptyset, \{x\}, \{x, y\}\}$
  $\text{Prem}(\mathbf{f}_c[\overline{x}](w)) = \{\overline{x}.\}$
  $\text{Prem}(\mathbf{f}_c[\overline{y}](w)) = \{\overline{y}., \overline{y}.x\}$

(13) a. If were $\overline{x}$, would (still) be $y$. *[false at $w \in xy$]*
b. If were $\overline{y}$, would (still) be $x$. *[true at $w \in xy$]*

(14) a. If it were raining, the streets would (still) be dry. *[false]*
b. If the streets were wet, it would (still) be sunny. *[true]*

# Ordering source




(15) If that match had been scratched, it would have lit.

(16) a. $\Pi = \left\{s, \overline{s}, o, \overline{o}, l, \overline{l}\right\}$

b. $\Pi_w = \left\{\overline{s}, o, \overline{l}\right\}$

c. $\mathbf{f}_c(w) = \left\{\emptyset, \{\overline{s}\}, \{o\}, \{\overline{s}, o, \overline{l}\}\right\}$

d. $\text{Prem}(\mathbf{f}_c[s](w)) = \{s., s.o\}$

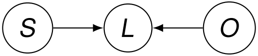
➽ (17) is correctly predicted to be true at *w*:

(17) If that match had been scratched, there would (still) have been oxygen.

BUT But the truth of (15) is not yet accounted for.

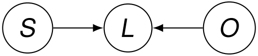
That's what the ordering source does.

# Ordering source




- I make minimal assumption as to what is in the ordering source **g**.
- Except that it respects a *Causal Markov Condition* relative to the causal structure.
- Roughly: If *p* is a (conditional) necessity/possibility under **g** given only *p*'s parents, it is also a necessity/possibility given its parents and other non-descendants. (For details, ask me for the paper.)

# Ordering source




(18) If that match had been scratched, it would have lit.

(19) a. $\text{Prem}(\mathbf{f}_c[s](w)) = \{s., s.o\}$

b. $\mathbf{g}_\ell(w) = \{\emptyset, \{o\}, \{(s \wedge o) \leftrightarrow l\}, \{o, (s \wedge o) \leftrightarrow l\}\}$

c. $\max \text{Prem}((\mathbf{f}_c[s] * \mathbf{g}_\ell)(w)) = \{s.o.((s \wedge o) \leftrightarrow l)\}$

➽ (18) comes out true at $w$.

Consider a world, $v$ just like $w$, except that oxygen was not present.

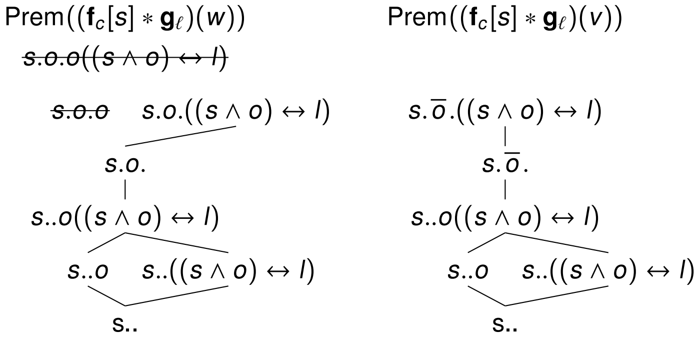
(20) a. $\text{Prem}(\mathbf{f}_c[s](v)) = \{s., s.\overline{o}\}$

b. $\mathbf{g}_\ell(v) = \{\emptyset, \{o\}, \{(s \wedge o) \leftrightarrow l\}, \{o, (s \wedge o) \leftrightarrow l\}\}$

c. $\max \text{Prem}((\mathbf{f}_c[s] * \mathbf{g}_\ell)(v)) = \{s.\overline{o}.(s \wedge o) \leftrightarrow l\}\}$

➽ (18) comes out false at $v$.

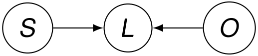
# Ordering source




- *o* is likely under **g**, but at *v* this is overridden by the facts.
- Modal base **f** pushes for *similarity* with the world of evaluation

  Ordering source **g** does not care; may pull away

# Ordering source




(21) If that match had not lit, it would not have been scratched.

(22) If that match had not lit, there would have been no oxygen.

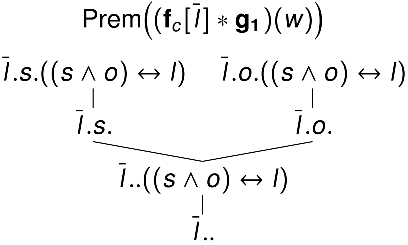
Consider an ordering source $\mathbf{g_1}_\ell$ just like $\mathbf{g}_\ell$, but indifferent towards $O_2$.

(23)
a. $\mathbf{f}_c(w) = \{\emptyset, \{s\}, \{o\}, \{s, o, l\}\}$
b. $\mathbf{f}_c[\bar{l}](w) = \left\{\bar{l}., \bar{l}.s, \bar{l}.o\right\}$
c. $\mathbf{g_1}_\ell(w) = \{\emptyset, \{(s \wedge o) \leftrightarrow l\}\}$
d. $\max \text{Prem}\Big((\mathbf{f}[\bar{l}] * \mathbf{g_1})(w)\Big) =$
$\left\{\bar{l}.s.((s \wedge o) \leftrightarrow l), \bar{l}.o.((s \wedge o) \leftrightarrow l)\right\}$

➻ Both (21) and (22) are false.

BUT each is true relative to *one* of the maximal sequences.

# Ordering source




- Multiple non-equivalent maximal sequences.
- I call this an *inquisitive* premise structure.

# Disjunctions

$$\text{Prem}((\{\{r\},\{s\}\} * \mathbf{f}_c)(w))$$

$r.pq$ | $s.pq$
$r.p$ | $s.p$
$r.$ | $s.$

(24) a. $\mathbf{f}_c(w) = \{\emptyset, \{p\}, \{p, q\}\}$
b. Assume that *'r or s'* denotes $\{\{r\},\{s\}\}$.

As a consequence, (25a) entails (25b):

(25) a. If were *'r or s'*, would be *t*.
b. If were *'r'*, would be *t* and if were *'s'*, would be *t*.

Similarly for interrogative antecedents (unconditionals).

The end

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